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A.U.W.E. Tech Note 176/65
JANUARY 1965
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SONAR TYPE 2001-X1
BEARING ACCURACY TRIAL OCTOBER 1964 [U]

BY

J. TURNBULL

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A.U.W.E. Technical Note 176/65
January 1965

TYPE 2001-X1 BEARING ACCURACY TRIAL OCTOBER 1964

by

J. Turnbull

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TYPE 2001-X1 BEARING ACCURACY TRIAL
OCTOBER 1964

PRÉCIS

1. Bearing accuracy measurements were made for the Type 2001-X1 passive sonar displays by comparing sonar and periscope bearings of a noise source.

2. Some results for the Sector Display and the PPI Display when used in their active modes were obtained during a later trial and are included in Appendix A.

CONCLUSIONS

3. The accuracies of the results for individual beams are limited by small sample sizes and the relative coarseness of the measuring technique. The accuracies for the displays, averaged over all beams, are summarised below, and are reasonably close to the limits given in the Agreed Characteristics for Type 2001.

Display	Average Error	Standard Deviation	RMS Error
HF Accurate Bearing	-0.46°	0.68°	$\pm 0.82^{\circ}$
LF Accurate Bearing	-0.43°	0.86°	$\pm 0.96^{\circ}$
HF Pen Recorder	-0.57°	0.50°	$\pm 0.77^{\circ}$
Sector Display (Passive Mode)	-0.43°	0.94°	$\pm 1.04^{\circ}$
Sector Display (Active Mode)	-0.43°	1.4°	$\pm 1.5^{\circ}$
PPI (Passive Mode)	-0.93°	0.95°	$\pm 1.3^{\circ}$
PPI (Active Mode)	-0.8°	1.28°	$\pm 1.5^{\circ}$

4. There is surprisingly little difference between the accuracies of the passive displays and in fact the r.m.s. error for the HF pen recorder is slightly less than for its associated "accurate bearing" display.

5. There is a bias towards negative errors for all displays (i.e. sonar bearing less than periscope bearing) but the distributions of negative errors between port and starboard beams are too inconsistent to suggest a possible misalignment of the periscope bearing ring or of the transducer array.

6. The active results show similar overall mean errors to the passive sector display and PPI figures but with larger standard deviations. The

larger standard deviations are probably due to the less controlled nature of the active measurements.

7. It should be emphasised that the results in this report are for relative sonar bearings read directly from the various displays. True bearing information, as required for fire control, is transmitted to the control room by coarse synchros and the errors introduced by the gyro compass and synchros may well be comparable with the sonar errors.

RECOMMENDATIONS

8. A more controlled experiment would be required for an absolute determination of bearing accuracy. For example, the submarine could be moored at periscope depth and sonar bearings of a movable noise source compared with accurate bearings by shore-based theodolites. Existing noise-range facilities might well be extended to allow these and other measurements associated with large, low-frequency sonar arrays to be made.

INTRODUCTION

9. Results are given in this report for the bearing accuracies of the Type 2001-X1 passive sonar displays. The measurements were made aboard HMS DREADNOUGHT in Bute Sound between 6th October and 8th October 1964. Some results for the active displays, obtained during a later trial, are included in Appendix A and the table in the Conclusion (paragraph 3).

10. Bearing accuracies were required for the following displays: (The r.m.s. errors given in the Agreed Characteristics for Type 2001 are shown in brackets.)

(a) HF Passive Accurate Bearing Display ($\pm \frac{3}{4}^{\circ}$).

(b) LF Passive Accurate Bearing Display ($\pm 1\frac{1}{2}^{\circ}$).

(c) Sector Display ($\pm 1^{\circ}$).

(d) HF Passive Pen Recorder ($\pm 2\frac{1}{2}^{\circ}$).

(e) PPI (No accuracy figures are quoted for this display in the Agreed Characteristics.)

11. The basis of the trial was a comparison between bearings by sonar and by HMS DREADNOUGHT's attack periscope. Various schemes using theodolites to provide a more accurate bearing standard were considered but were either found to be impracticable or too difficult to arrange in the time available.

METHOD

12. A wide-band noise was transmitted by a transducer suspended below an anchored MFV. HMS DREADNOUGHT made a series of runs at periscope depth designed to sweep the noise source slowly through the sonar beams from ahead to 120° Port or 120° Starboard, spending one or two minutes in each beam. Port and Starboard runs were alternated and a total of 26 runs were made during the trial. Ranges varied from 6000 to 1000 yards and periscope visibility was generally adequate at these ranges.

13. Direct readings from the sonar bearing displays and the periscope bearing ring were tabulated against the time from synchronised stop watches every 10 or 20 seconds throughout each run. All bearings were relative to ship's head to avoid the gyro errors which can occur when frequent changes of course are made. Radar range-time data were also tabulated.

14. Periscope bearings, PPI bearings and radar ranges were read off and recorded by the AUWE trials team. All other sonar bearings were read off by HMS DREADNOUGHT's sonar operators.

15. A rough check of the number of results obtained for each beam was kept during the trial to ensure statistically significant results, despite the relatively large random errors inherent in the method although subsequent detailed analysis showed that this aim was not always realised.

Recording Errors

16. Periscope and sonar bearing scales were graduated every degree and could, with care, be read to the nearest $\frac{1}{4}^{o}$. In practice, because readings were taken quickly, there was a bias towards whole numbers. This is clearly shown in Figure 1 which gives distributions of 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ degree readings for two sonar and two periscope recorders. Such rounding-off errors obviously reduce the significance of small samples.

Periscope Accuracy

17. No data are available for the periscope accuracy other than the fact that, during installation, the bearing ring was aligned so that its zero corresponded closely to the ship's fore and aft line. However, it is probably reasonable to assume that systematic errors form only a small fraction of the r.m.s. periscope errors.

Treatment of Results

18. Sonar bearings for the various runs were grouped into beams by taking readings within $\pm 2^{o}$ of the nominal axes ($\pm 10^{o}$ for the PPI beams). The error within a beam is assumed to be constant. Periscope and sonar readings were not usually coincident in time and linear interpolation between points was used in obtaining the differences. These differences and the corresponding ranges from the radar data were put on punched tape. A simple computer programme was then used to correct for the parallax caused by the separation of periscope and transducer array (32 yards) and to obtain the mean difference and standard error of the mean $\left(\frac{\text{Standard deviation}}{\sqrt{\text{number of results}}}\right)$ for each beam. The significance of the results was tested by applying the "t"-test for small samples. i.e. the mean difference for a beam is assumed to be significantly different from zero if the value of $t = \frac{\text{mean difference}}{\text{standard error}}$ has less than a 5% probability of being exceeded by chance. Tables of t for various sample sizes and probability levels are given in most text books of statistics.

19. The beams are formed from different delay lines and different sections of the transducer array and, as will be seen from the results, there are significant differences between the bearing errors for many of the beams so that a single, true bearing error cannot be assumed for a particular display. The results for a display are therefore summarised by the average and standard deviation of the mean differences for the beams rather than by the average over all the data.

RESULTS

20. The results given are specifically for the Type 2001-X1 sonar fitted in HMS DREADNOUGHT. They are typical of the results to be expected for future Type 2001 sonars but variations are possible because of equipment tolerances.

HF Passive Accurate Bearing Display

21. Table 1 gives the mean differences between sonar and periscope bearings and the corresponding standard errors. Figure 2(a) shows the distribution of errors. The following conclusions are drawn from these results.

(a) Confidence limits for these mean errors are wide, particularly for the smaller samples but at least twenty-six of the forty-seven beams have mean errors which are significantly different from zero (at a 5% level of significance).

(b) Thirty-seven beams have mean errors of less than $\pm 1^{\circ}$ and only the starboard beams have errors greater than 1°.

(c) All starboard beam errors are negative, i.e. sonar bearing less than periscope bearing.

(d) The average error for the display is -0.46° with a standard deviation of 0.68°. The r.m.s. error about zero mean is $\pm 0.82^{\circ}$.

(e) Results for the 25° and 55° starboard beams are suspiciously high, possibly because of a rather high bearing rate through these beams, and are not supported either by results for other displays or by previous measurements of the HF Correlograms. Neglecting these two beams gives an overall r.m.s. error of $\pm 0.73^{\circ}$, just within the Agreed Characteristics.

LF Passive Accurate Bearing Display

22. These results are given in Table 2 and Figure 2(b) and are summarised as follows:-

(a) At least twenty-five beams have significant mean errors.

(b) All the beams measured have mean errors less than $\pm 2^{\circ}$ and thirty-eight of these errors are less than $\pm 1\frac{1}{2}^{\circ}$. All port beams have negative errors.

(c) The mean error for the display is -0.43° with a standard deviation of 0.86°. The r.m.s. error about zero mean is $\pm 0.96^{\circ}$.

(d) Comparing HF and LF results, the overall mean errors are very similar and differences between errors for corresponding beams rarely exceed $\pm 2^{\circ}$.

(e) There is however no correlation between the results for HF and LF beams (correlation coefficient = -0.01) which supports the absence of significant systematic periscope errors.

Sector Display (Passive Mode)

23. The sector display results are given in Table 3 and Figure 3(a) and are summarised below. These results refer to the bearing of the noise spoke on the sector display cathode ray tube and not to the bearing of a target echo. Bearing accuracy results for active operation of the sector display were obtained in a later trial and are discussed in Appendix A.

(a) At least sixteen of the beams have significant mean errors.

(b) Twenty-eight beams have mean errors of less than $\pm 1^{\circ}$.

(c) The mean error for the display is -0.43° with a standard deviation of 0.94°. The r.m.s. error is $\pm 1.04^{\circ}$.

HF Passive Pen Recorder

24. These results are given in Table 4 and Figure 3(b) and are summarised as follows:-

(a) At least twenty-four beams show significant departures from zero bearing error.

(b) Thirty-six beams have mean errors of less than 1°.

(c) The mean error for the display is -0.57° with a standard deviation of 0.5°. The r.m.s. error about a zero mean is $\pm 0.77^{\circ}$.

PPI Display (Passive Mode)

25. The results for the PPI are given in Table 5 and the following conclusions are drawn:

(a) Ten of the twelve beams have errors which are significantly different from zero.

(b) Eleven beams have mean errors of less than 2°.

(c) The mean error for the display is -0.93° with a standard deviation of 0.95°. The r.m.s. error is $\pm 1.3^{\circ}$.

TABLE 1: HF PASSIVE ACCURATE BEARING RESULTS

Beam	PORT BEAMS			STARBOARD BEAMS		
	Number of Results	Mean Difference Degrees	Standard Error Degrees	Number of Results	Mean Difference Degrees	Standard Error Degrees
0	24	0.76	.10			
5	11	0.53	.07	16	-0.61	.10
10	9	0.48	.15	7	-0.21	.50
15	12	-0.24	.09	10	-1.33	.20
20	9	0.16	.11	11	-1.01	.14
25	9	-0.96	.10	7	-2.28	.14
30	10	0.03	.11	13	-0.86	.13
35	8	0.13	.18	11	-0.81	.10
40	4	0.80	.20	8	-0.84	.69
45	16	0.52	.09	5	-0.17	.18
50	4	-0.11	.16	5	-0.59	.14
55	7	-0.63	.19	4	-1.86	.50
60	9	0.60	.11	8	-0.46	.20
65	6	0.47	.06	5	-0.11	.26
70	4	0.36	.16	9	-0.64	.11
75	3	0.40	.20	4	-1.31	.13
80	3	-0.31	.11	5	-0.65	.08
85	5	-0.27	.11	6	-1.02	.10
90	6	-0.34	.16	5	-1.14	.26
95	5	-0.40	.23	6	-1.48	.19
100	6	-0.37	.15	5	-0.82	.29
105	7	-0.38	.10	5	-0.89	.17
110	8	-0.49	.11	3	-1.10	.29
115	13	-0.92	.07	5	-1.40	.12

TABLE 2: LF PASSIVE ACCURATE BEARING RESULTS

Beam	PORT BEAMS			STARBOARD BEAMS		
	Number of Results	Mean Difference Degrees	Standard Error Degrees	Number of Results	Mean Difference Degrees	Standard Error Degrees
0	20	0.93	.21			
5	19	-0.43	.14	13	-0.46	.33
10	11	0.08	.16	11	0.06	.48
15	18	-0.42	.17	15	-0.31	.24
20	5	-0.13	.46	6	0.75	.16
25	5	-1.21	.05	7	-0.64	.46
30	3	-1.59	.08	4	-0.63	1.12
35	11	-0.57	.23	4	-0.62	.65
40	8	-1.42	.26	4	0.15	.39
45	8	-1.46	.20	4	-0.80	.57
50	2	-1.54	.40	6	-0.10	.27
55	4	-1.64	.32	5	1.82	.50
60	5	-1.83	.21	9	0.18	.40
65	-	-	-	2	1.55	.49
70	8	-0.88	.19	5	1.03	.39
75	3	-1.66	.00	6	0.35	.63
80	6	-1.16	.26	9	0.66	.28
85	9	-1.49	.24	9	0.63	.22
90	10	-0.97	.31	10	-0.19	.38
95	8	-0.22	.43	10	-0.04	.41
100	10	-1.20	.22	12	-1.52	.26
105	3	-0.70	.21	11	-0.20	.48
110	6	-0.84	.37	13	-0.07	.42
115	3	-1.02	.44	4	0.12	.96

TABLE 3: SECTOR DISPLAY RESULTS

Beam	PORT BEAMS			STARBOARD BEAMS		
	Number of Results	Mean Difference Degrees	Standard Error Degrees	Number of Results	Mean Difference Degrees	Standard Error Degrees
0	24	-0.49	0.11			
5	5	-1.25	0.36	11	0.89	0.19
10	5	0.07	0.26	13	0.74	0.21
15	6	-1.79	0.34	7	-0.08	0.24
20	5	-0.42	0.52	4	0.78	0.50
25	2	-1.34	0.47	5	-0.24	0.08
30	10	-0.37	0.27	5	-0.17	0.24
35	6	-0.74	0.39	-	-	-
40	7	0.07	0.46	2	0.81	0.26
45	8	-0.12	0.30	6	1.01	0.34
50	5	-1.15	0.32	6	-0.06	0.22
55	7	-1.38	0.22	6	0.72	0.32
60	7	-0.87	0.41	5	0.49	0.38
65	7	-0.29	0.31	7	1.09	0.39
70	4	-0.58	0.59	6	1.04	0.33
75	4	-1.72	0.26	4	0.74	0.80
80	6	-1.34	0.33	6	0.54	0.40
85	5	-1.34	0.75	4	0.12	0.87
90	5	-1.26	0.22	-	-	-
95	3	-2.27	0.24	6	-0.24	0.30
100	7	-1.63	0.29	9	-0.40	0.17
105	5	-2.08	0.27	9	-0.13	0.25
110	7	-1.75	0.15	3	-0.12	0.55
115	7	-2.07	0.49	6	-0.93	0.36

TABLE 4: HF PASSIVE PEN RECORDER RESULTS

Beam	PORT BEAMS			STARBOARD BEAMS		
	Number of Results	Mean Difference Degrees	Standard Error Degrees	Number of Results	Mean Difference Degrees	Standard Error Degrees
0	31	0.15	0.15			
5	10	0.50	0.19	14	-0.77	0.26
10	9	0.09	0.32	10	-0.02	0.32
15	13	-0.17	0.22	13	-0.09	0.20
20	9	-0.99	0.34	12	-0.89	0.22
25	8	-0.56	0.22	9	-1.16	0.23
30	10	-1.11	0.24	12	-0.74	0.15
35	9	-0.75	0.32	12	-0.56	0.18
40	6	0.20	0.60	10	-0.60	0.22
45	17	0.29	0.20	6	-0.34	0.49
50	9	0.16	0.40	-	-	-
55	8	0.44	0.46	5	-1.10	0.40
60	10	-0.26	0.28	8	-0.89	0.16
65	9	-0.44	0.19	4	0.13	0.16
70	4	0.06	0.24	8	-1.12	0.42
75	5	-0.59	0.35	7	-0.31	0.43
80	4	-0.45	0.09	8	-0.75	0.23
85	6	-0.95	0.16	7	-0.45	0.39
90	6	-1.97	0.78	7	-0.90	0.19
95	6	-1.11	0.41	6	-0.94	0.33
100	5	-1.19	0.11	7	-0.75	0.23
105	7	-0.59	0.17	7	-0.42	0.35
110	8	-0.81	0.19	5	-1.15	0.50
115	13	-1.30	0.22	10	-1.00	0.25

TABLE 5: PPI RESULTS

Beam	PORT BEAMS			STARBOARD BEAMS		
	Number of Results	Mean Difference Degrees	Standard Error Degrees	Number of Results	Mean Difference Degrees	Standard Error Degrees
10	20	-0.56	0.12	20	-0.47	0.10
30	20	-0.79	0.16	20	-1.45	0.14
50	20	-1.78	0.10	20	0.77	0.15
70	10	-2.58	0.58	20	0.26	0.09
90	19	-0.80	0.23	13	-0.11	0.22
110	9	-1.88	0.05	18	-1.80	0.06

APPENDIX A: SECTOR DISPLAY AND PPI ACTIVE BEARING ACCURACIES

1. The opportunity was taken during a recent initial-detection trial (November 1964) to measure the Sector Display and PPI bearing accuracies in the active mode.

2. The method adopted was for HMS DREADNOUGHT to steer a constant course relative to a surface-ship target for long enough to take about a dozen readings of sonar and periscope bearings. Sonar and periscope readings were taken at roughly the same time but no times were actually noted and for the purposes of analysis, readings were assumed to be coincident. Measurements were made for seventeen different bearings between 110° Port and 110° Starboard at an average range of 6000 yards.

3. Mean errors for the various bearings are given in Table 6 below. Errors averaged over all bearings for the two displays are as follows:-

(a) Sector Display: Average Error -0.43°, Standard Deviation 1.4°, r.m.s. Error ± 1.5°.

(b) PPI: Average Error -0.8°, Standard Deviation 1.28°, r.m.s. Error ± 1.5°.

TABLE 6: SECTOR DISPLAY AND PPI ACTIVE RESULTS

Port Bearing	Mean Error, degrees		Starboard Bearing	Mean Error, degrees	
	Sector Display	PPI		Sector Display	PPI
87°	-3.14	+0.84	110° 98°	-0.35 +0.17	-2.8 -
75°	-2.15	-2.9	82°	+0.25	-2.7
62°	-2.05	-2.0	67°	+1.4	+0.13
55°	-1.45	-0.7	53°	+0.25	+0.3
44°	-0.7	-0.13	38°	+1.9	-1.2
31°	-1.85	-2.2	25°	+0.6	+0.2
22°	-1.7	-0.12	10°	+1.5°	+1.0
9°	-1.1	-0.14	4°	+1.1°	-0.5

4. As for the corresponding passive results, both Sector Display and PPI show a strong bias towards negative errors, particularly in the port beam, but the actual errors are considerably higher in the active case. There is a tendency for the bearing errors to be larger for broad-aspect targets but this is not conclusive.

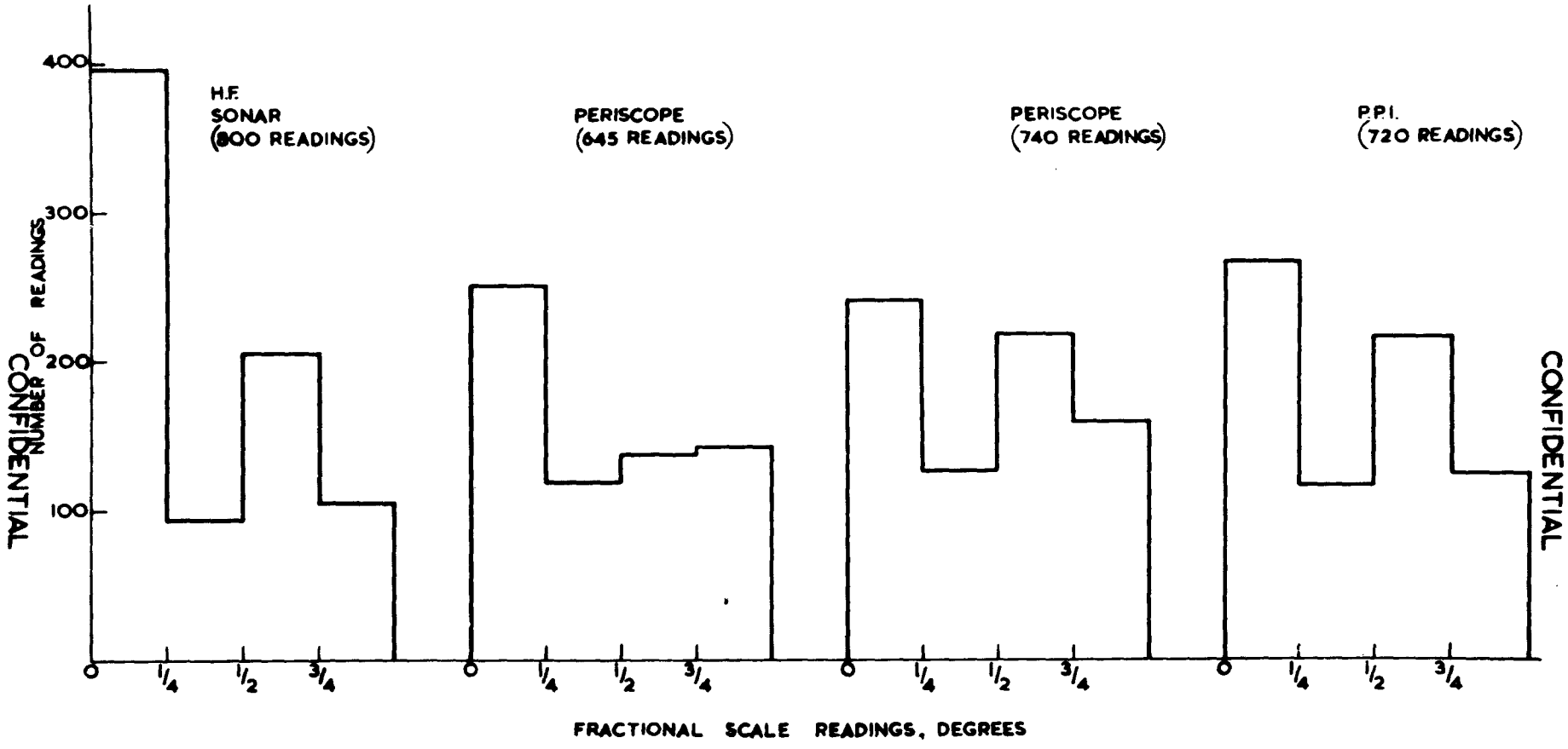
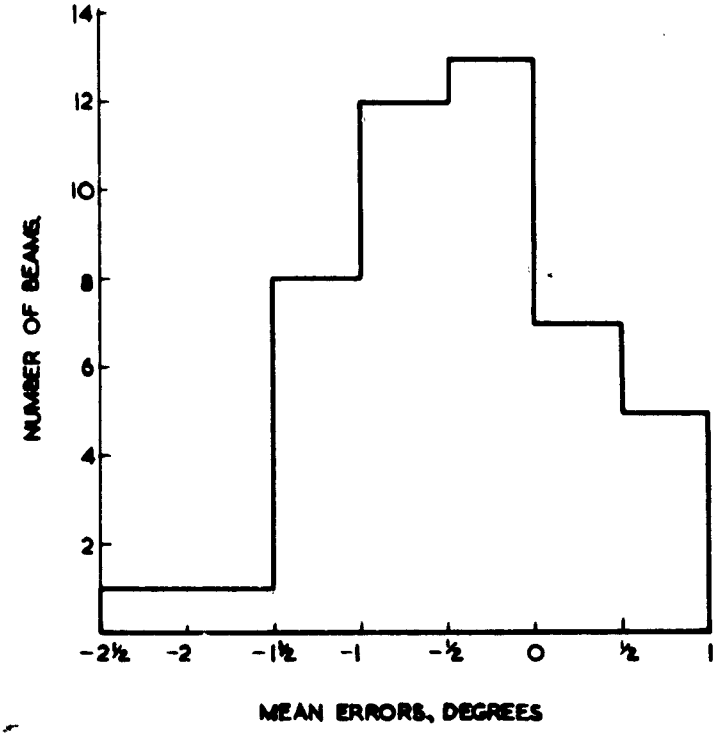


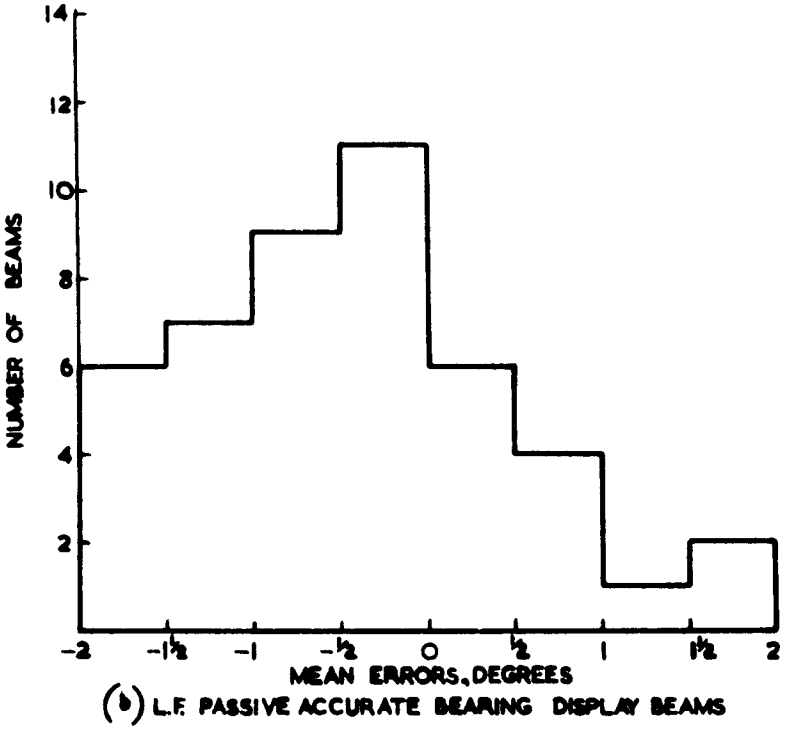
FIG.I DISTRIBUTIONS OF SONAR AND PERISCOPE READINGS

FIG.I

FIG 2 a&b

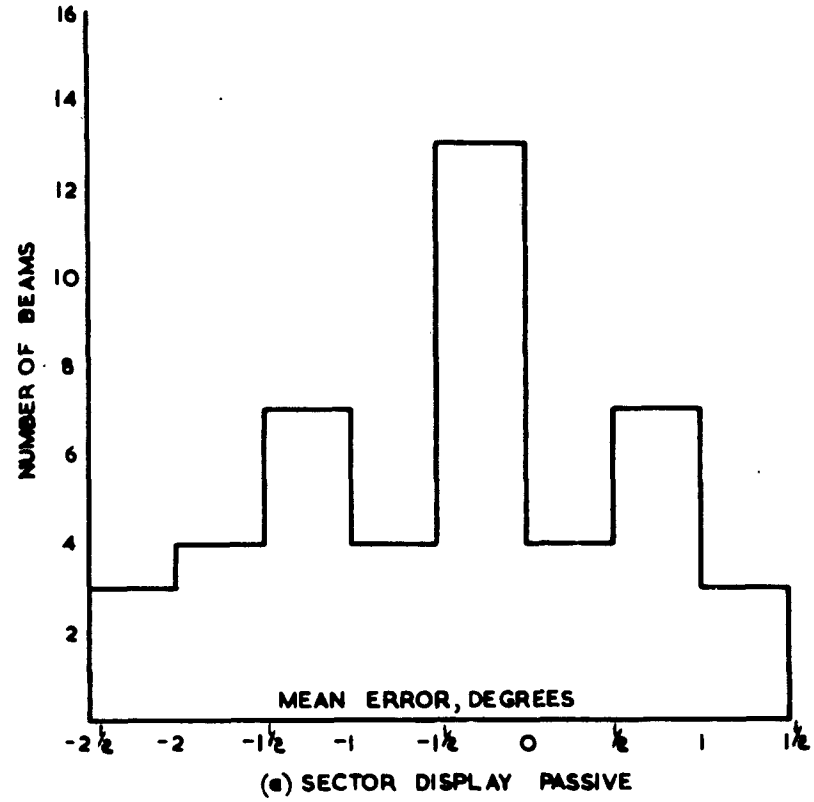


(a) H.F. PASSIVE ACCURATE BEARING DISPLAY BEAMS

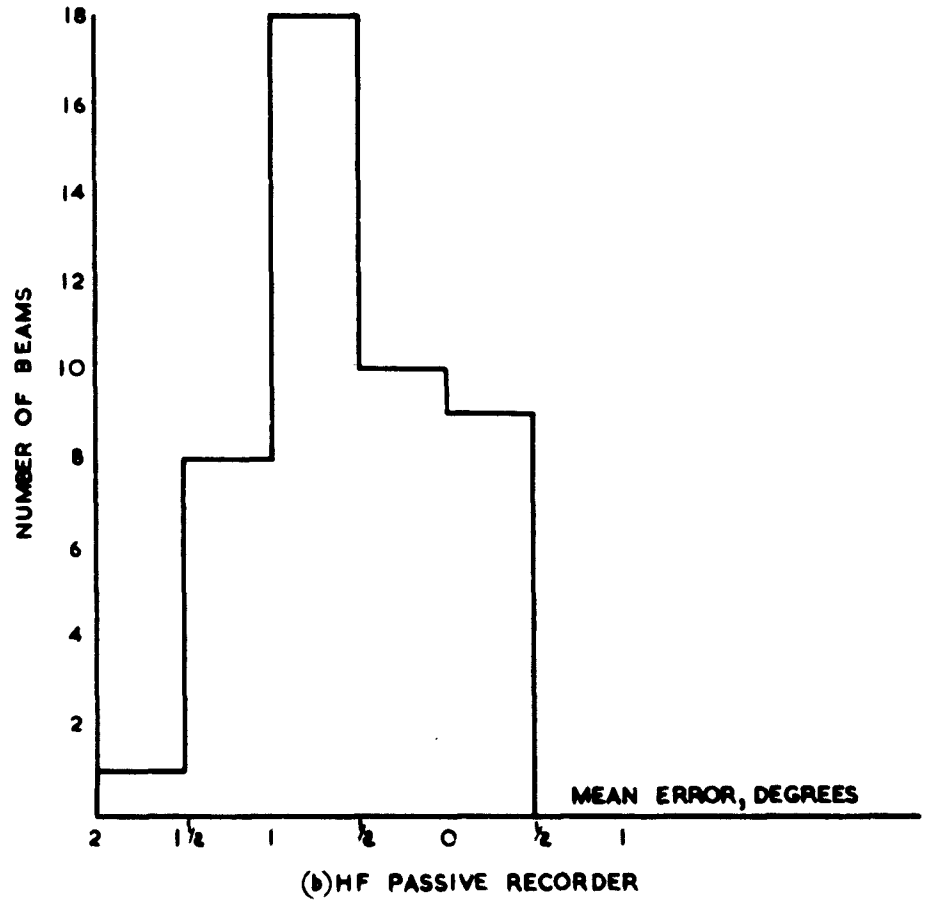


(b) L.F. PASSIVE ACCURATE BEARING DISPLAY BEAMS

FIG.2a&b DISTRIBUTIONS OF MEAN ERRORS



(a) SECTOR DISPLAY PASSIVE



(b) HF PASSIVE RECORDER

FIG. 3a&b. DISTRIBUTIONS OF MEAN ERRORS

U.K. ABSTRACT NO.

(A)	Country of Origin	UNITED KINGDOM
(B)	Establishment of origin with short address	Admiralty Underwater Weapons Establishment, Portland.
(C)	Title of Report	Type 2001-X1 Bearing Accuracy Trial October 1964
(D)	Author	J. Turnbull.
(E)	Pages and Figures	15 pages ((i) - (ii) (1 - 13)) Figs. 3.
(F)	Date	January, 1965.
(G)	Originators Reference	Technical Note 176/65
(H)	Security Grading	CONFIDENTIAL
(J)	Abstract	Bearing accuracies of the Type 2001-X1 active and passive sonar displays were measured by comparing sonar and periscope relative bearings. The R.M.S. bearing errors of Type 2001-X1 were not greater than $\pm 1^{\circ}$ for the L.F. and H.F. passive displays and not greater than $\pm 1.5^{\circ}$ for the P.P.I. and Sector Displays.

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Bearing accuracies of the Type 2001-X1 active and passive sonar displays were measured by comparing sonar and periscope relative bearings. The R.M.S. bearing errors of Type 2001-X1 were not greater than $\pm 1^{\circ}$ for the L.F. and H.F. passive displays and not greater than $\pm 1.5^{\circ}$ for the P.P.I. and Sector Displays.

CONFIDENTIAL

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January, 1965.
J. Turnbull.

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